

Voltage converter for converting an input voltage to an output voltage and driving circuit comprising a voltage converter

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The invention regards a voltage converter for converting an input voltage to an output voltage comprising a plurality of cascaded voltage multipliers and control circuitry for controlling the plurality of voltage multipliers. Further, the invention leads to a driving circuit comprising such a voltage converter.

10 A voltage converter, such as a charge pump device or other device comprising voltage multipliers, is used to generate a higher voltage than a supply voltage available for an application. A voltage converter may have several voltage multipliers arranged in stages in a kind of cascade. A charge storage element of the first stage may be charged upon a switching event of a driver driving the first stage. A
15 further switching element of the first stage may be in an opened position in this case. Thereafter the further switching element may be closed so that the charge may be supplied to the next stage. The charge storage element of the subsequent stage may then be charged upon a switching event of a driver driving the subsequent stage. Thus, a charge stored in the first stage is forwarded to one or more subsequent stages, where it
20 is added to the charge of such a subsequent stage, so that a higher voltage is generated and can be provided to a device of an application.

An advantage of using charge pumps is that generally no additional bypass switches are needed and a voltage converter of such kind can thus be relatively simply construed. A charge pump may be composed of a cascade of several stages,
25 whereby each stage contains at least one switch or diode, a charge-storing element, usually realized as a capacitor, and a driver. The driver commands the charge storing elements and may be operated by periodical signals or phases.

A voltage converter is known from a publication in the IEEE Journal of solid-state circuits, vol. SC-11, No. 3, June 1976, pages 374 - 378. In the publication the

voltage converter output voltage serves to provide a high supply voltage in a NMOS integrated circuit application. Further, a voltage converter may be used in a liquid crystal display (LCD) driver as an application to generate a bias voltage required by a driving scheme. Yet another application is the generation of a high voltage necessary to write a flash memory.

Basic architectures of voltage converters employed in LCD-driving IC's may be programmable with regard to the application to which the voltage is supplied. Such a voltage converter as that mentioned in the introduction allows an appropriate number of selected voltage multipliers to be activated, i.e., if a relatively low output voltage is desired, the number of active voltage multipliers is relatively low, whereas if a relatively high output voltage is desired, the number of active voltage multipliers is relatively high. Thus, an unnecessarily high number of active voltage multipliers can be avoided, thereby avoiding a low power efficiency of the voltage converter. The non-active, i.e. disabled voltage multipliers should be bypassed by means of switches or shunted parallel to an active voltage multiplier. Some types of voltage multiplier allow a switch within the voltage multiplier to be used, in order to bypass the respective voltage multiplier if it is in a non-active operating mode.

LCD modules find a large application in cellular phones and other hand-held tools such as organizers, laptops, PDAs etc. An available supply voltage for an analogue block may be 2.8 V and an LCD graphic display may be driven with voltages of 6 V to 16 V and should also be operable within a large range of supply voltages. A range of output voltages is desired for different kinds of applications.

However, in the LCD driving integrated circuits (IC's) the trend nowadays is towards developing ever increasing resolutions and color displays, in particular for mobile terminals such as phones, PDA's etc. These displays need a large current at a voltage approaching 20 V, which has to be generated by the LCD-driving IC. In the actual LCD-driving IC's the amount of charging capability of a charge storage element, particularly a capacitor value, is limited and the amount of necessary currents is increasing. The achievable voltage and required current are subject to compromise, but still the need for an increased current capability is generally becoming more acute. In particular, an increasingly large current is usually drawn from a smaller capacitor and

the voltage drop due to a charge transfer is increasingly large. This large voltage drop may be multiplied by all the stages of a voltage converter, thus degrading the performance.

This is where the invention comes in, the object of which is to propose
5 an apparatus and a method of converting an input voltage to an output voltage, whereby an improved current capability should be achieved.

As regards the apparatus the object is solved by a voltage converter according to claim 1, which claims a voltage converter for converting an input voltage to an output voltage comprising a plurality of cascaded voltage multipliers and control
10 circuitry for controlling the plurality of voltage multipliers, wherein in accordance with the invention the control circuitry comprises a switching means for activating at least one first voltage multiplier selected from the plurality of voltage multipliers and for switching at least one further voltage multiplier located in the cascade before the first voltage multiplier in the same way as the first voltage multiplier.

15 Further, as regards the apparatus the object is solved by a driving circuit according to claim 14, which is a driving circuit, comprising a voltage converter at present, in particular a driving circuit for a display device.

As regards the method the object is solved by a method of converting an input voltage to an output voltage by means of a voltage converter comprising a
20 plurality of cascaded voltage multipliers, wherein in accordance with the invention at least one first voltage multiplier selected from the plurality of voltage multipliers is activated and at least one further voltage multiplier located in the cascade before the first voltage multiplier is switched in the same way as the first voltage multiplier.

The proposed invention has arisen from the desire to further increase the
25 current capability of a voltage converter or a driving circuit, in particular when not all stages of a voltage converter are used for multiplying a voltage. The invention has realized that conventionally the unused multipliers and/or charge storage elements of a multiplier merely play a passive role. They merely appear as decoupling or buffering elements. According to the inventive idea now these are used to increase the strength of
30 a first voltage multiplier selected from the plurality of voltage multipliers, when switched as proposed by a switching means. In particular when using a charge pump as

a voltage multiplier, if not all stages of the charge pump are used for a pumping charge, the unused capacitors no longer play a passive role in decoupling or buffering capacitors, but are used to increase the strength of the first pumping stage together with their bottom plate driver.

5 As a main advantage of the invention the first and further voltage multiplier may be switched in the same way by changing the logic circuitry only. Advantageously no increase in area or number of analogue parts is foreseen. Depending on the number of stages and the supply voltage an increase in current capability of 10 % to 15 % may thus be achieved.

10 Further, developed configurations of the invention are outlined in the dependent claims.

 Switching comprises activating and disabling. To activate the respective stage is preferably switched to the supply voltage V_{dd} potential. The multiplier is thus in an active mode. To disable the respective stage may be switched to ground voltage. The
15 multiplier is thus in a passive mode.

 Advantageously the first voltage multiplier is one of a number of activated voltage multipliers also located in the cascade at a second or higher order stage at most, in particular located in a sequence of stages at the end of the cascade.

 Advantageously the further voltage multiplier is one of a number of
20 further voltage multipliers also located at the first or higher order stages of the cascade, in particular located in a sequence of stages at the beginning of the cascade.

 At least one of a plurality of voltage multipliers is preferably formed by a charge pump.

 Such a voltage pump comprises a charge storage element, in particular a
25 capacitor, a switch, in particular a MOSFET switch, and a driver, in particular a bottom plate driver. The charge storage element may be on-chip or off-chip.

 Also, one or more of the voltage multipliers may have at least one clock input. The control circuitry is preferably connected to a clock input for supplying a clock signal to a voltage multiplier for controlling the voltage multiplier.

30 In a preferred configuration the voltage converter is programmable. In particular the switching means is a programmable logic device. Such a logic device is

advantageously driven by a programming means for operating the switching means as a function of the output and/or input voltage, i.e. depending on the application. Thus, the multiplication factor of a voltage converter is advantageously adapted to the actual application. In particular, not all stages of the converter may be used to generate an
5 output voltage below the maximal possible voltage, when all stages of the converter are to be used.

In particular, the programming means comprises a software code section capable of activating one or more first voltage multipliers in the case of an input voltage, which is insufficient for the actual application, i.e. the respective multipliers are
10 held in an active operating mode. Further, the programming means may comprise a software code section for disabling a number of voltage multipliers selected from the plurality of voltage multipliers in the case of an input voltage sufficient for the actual application, i.e. the respective multipliers are held in a disabled or passive operating mode. In particular for this specific situation the programming means preferably
15 comprises a software code section capable of selecting one or more further voltage multipliers from the disabled voltage multipliers to be switched in the same way as the first voltage multiplier.

Advantageously a re-configurable voltage converter constitutes one of the above measures or a combination thereof.

20 A voltage converter and/or a driving circuit as proposed works advantageously under a current load of 0.1 mA to 10 mA.

Preferred embodiments of the invention will now be described in a detailed description with reference to the accompanying drawings. These are meant to show examples to clarify the proposed concept in connection with the detailed
25 description of the preferred embodiment and in comparison to prior art. While the considered preferred embodiment will be illustrated and described, it should of course be understood that various modifications and changes in form or detail could readily be made without departing from the spirit of the invention. It is therefore intended that the invention may not be limited to the exact form and detail shown and described herein
30 nor to anything less than the whole of the invention disclosed herein and as claimed hereinafter. Further the features described in the description, the drawings and the

claims disclosing the invention may be essential for the invention, considered alone or in combination.

The drawing shows in:

- Figure 1: a schematic charge pump architecture;
- 5 Figure 2a: a schematic view of a prior art charge pump-switching scheme;
- Figure 2b: a charge pump-switching scheme according to the preferred embodiment;
- Figure 2c: an equivalent circuit of the proposed embodiment of Figure 2b;
- Figure 3: a preferred display device embodiment comprising a driving
- 10 circuit containing a preferred charge pump.

The preferred voltage converter embodiment is described with regard to a programmable charge pump as shown in Figure 1. A programmable charge pump 1 has a series of stages $S_1 \dots S_N, S_{N+1} \dots S_{\max}$ each containing a capacitor C_{stage} as a charge storage element, a MOSFET as a switch $Sw_1 \dots Sw_N, Sw_{N+1} \dots Sw_{\max}$ and a bottom plate driver as a switching means (not shown). Each respective charge pumps $S_1 \dots S_N, S_{N+1} \dots S_{\max}$ further comprises a buffer $BF_1 \dots BF_N, BF_{N+1} \dots BF_{\max}$ with an input $I_1 \dots I_N, I_{N+1} \dots I_{\max}$, e.g. for receiving a clock input signal and a voltage V_{dd} as indicated in the Figure. An input voltage V_{dd} is generated by a voltage source between the input terminal IP and the ground terminal GND and is supplied to the charge pump device 1. The

20 stages are connected in a cascade, one after each other. With every stage one input supply voltage V_{dd} may be gained. This is true for the ideal situation of no output current. The clock may also be generated adaptively with several phases. The above-outlined ideal situation has to be corrected as there are internal losses, these losses being mainly due to dissipated currents by switch resistances when in an "on"-position and

25 one or more bottom plate drivers. A single or a plurality of bottom plate drivers are capable of actuating each of the charge pumps $S_1 \dots S_N, S_{N+1} \dots S_{\max}$ and in particular the switches $Sw_1 \dots Sw_N, Sw_{N+1} \dots Sw_{\max}$. A driver is operable when connected to each of the charge pumps $S_1 \dots S_N, S_{N+1} \dots S_{\max}$ in a suitable way, e. g. by operating the input terminals IP, $I_1 \dots I_N, I_{N+1} \dots I_{\max}$ and the switches $Sw_1 \dots Sw_N, Sw_{N+1} \dots Sw_{\max}$. A state

30 in which a charge pump may be operated is indicated in Figures "1" and "2" respectively. In the output stage with a capacitor C_{buffer} the output voltage V_{out} is

generated between the output terminal IO and the ground terminal GND.

The stages $S_1 \dots S_N, S_{N+1} \dots S_{W_{\max}}$ of Figure 1 and the sizing thereof are identical to each other in their construction. However, this is not the optimal case and has been chosen only to achieve a simple design with the advantage of a short design time. Further developed voltage converter embodiments may preferably be designed in a different way. In particular, stages $S_1, S_2 \dots S_N$ close to the voltage booster input may have a stronger layout than $S_N, S_{N+1} \dots S_{\max}$ closer to the output.

The improvement of the preferred charge pump embodiment with regard to conventional charge pumps is explained in the following.

In a single clock cycle the charge is usually transferred from the capacitor of a stage N into the capacitor of the following stage N+1. At the beginning of the clock cycle, the capacitor of the stage N+1 is not discharged completely. In fact, not all of its charge Q acquired in the preceding cycle is usually transferred to the next stage N+2 within one cycle. In general, the quantity $Q = I_{\text{load}}/2f$ is transferred, where f is the clock frequency. This corresponds to a voltage difference of $\Delta U = Q/C = I/2fC$. If the capacitor has a large capacitance C for the same I_{load} the voltage drop ΔU due to this current is smaller than with a capacitor of small capacitance, which can be drawn from the latter formula. However, in the actual LCD-driving IC's the capacitor value is limited and therefore the amount of currents is becoming increasingly large. Usually a current is in the order of 1 mA and higher. Such a voltage drop has to be assumed for each stage 1 ... N. Therefore, the assumption of an efficiency of 100 % $I_{\text{load}} = I_{\text{supply}}/N$ also holds. As a result the voltage and current achieved are subject to compromises, which have to be made for each application.

As the first stage of the charge pump experiences the following stages as a load, this means that the need of a big current capability becomes more and more acute when approaching the beginning stage S_1 of the chain of stages $S_1 \dots S_N, S_{N+1} \dots S_{\max}$. In particular, if a large current is drawn from a small capacitor C_{stage} , then the voltage drop ΔU due to the charge transfer is large as well. As outlined, this charge voltage drop is multiplied by the following stages N-1 times, thus degrading the performance of a conventional charge pump, as an example of a conventional voltage converter.

To remove such a problem the multiplication factor is programmed as outlined in the following:

Assuming $V_{out} = N_{max} \cdot V_{dd}$ one may choose to generate only $V_{out} = N \cdot V_{dd}$ by setting the $(N_{max} - N)$ switches Sw to the conducting state and, correspondingly, the bottom plate drivers permanently to ground GND. In this case the first active charge pump A of Figure 2a is not the first charge pump in the cascade, but may be any charge pump in the cascade, e. g. in stage S_{N+1} . This means that the respective charge pumps located before the active one are disabled, as is indicated in Figure 1 by "0". Thus $(N_{max} - N)$ stages are disabled. Within the function of the whole device the disabled stages usually merely play a filtering element role for the input supply voltage V_{dd} or as a charge tank permanently charged by the input supply voltage V_{dd} . This in fact has a certain benefit with regard to the performance of the charge pump device. However, it also has a drawback, the disabled stages are used only as a decoupling element or a "charge tank" in front of the pumping stages and therefore only play a passive role.

According to the preferred embodiment shown in Figure 2b use is made of these disabled stages and in fact results in an increase of the current capability of a charge pump device 1. To put it simply, the preferred embodiment introduces a means of more effectively using the "disabled" stages.

As an example the following describes a way of reinforcing the first active pumping stage A shown in Figure 2b, in order to achieve the desired output voltage in less time and increase the current provided by the charge pump.

The reinforcement of first pumping stage A is only described with regard to Figures 2b and 2c to illustrate the basic principle of effectively "using" the "disabled" stages, e.g. stages $S_1 \dots S_N$, and may be generalized according to the demands of an actual application.

Figure 2a illustrates the situation in which a first stage is forced to ground voltage by the bottom plate driver.

The preferred embodiment 1b is illustrated in Figure 2b. A logic device is giving the bottom plate driver a command to switch the first stage 1st between V_{dd} (activated) and ground (disabled) in the same way as for the first active pumping stage A. The first active pumping stage A in Figure 2b is in fact the second stage or a higher

stage S_{N+1} located in the cascade at most. The circuit 1b of Figure 2b is equivalent to 1c in Figure 2c, from which it is immediately clear that the input stage $A = A'$ now has a capacitance of $2 \cdot C_{\text{stage}}$ and the equivalent resistance of A' is $R_d/2$ because the two bottom plate drivers are connected in parallel. Consequently, the charge stored in the second stage $A = A'$ at the end of the charge transfer is higher than in a conventional charge pump device circuit as shown in Figure 2a.

The attached graphs Ga and Gb in Figures 2a and 2b correspond to circuits 1a and 1b in Figure 2a and Figure 2b respectively. From the graphs it is clear that in the second stage A the charge transferred into the capacitor will be passed forward to stage B in the preferred embodiment 1b of Figure 2b is $Q = I_{\text{load}}/3f$ instead of $Q = I_{\text{load}}/4f$ in a conventional circuit 1a of Figure 2a.

It should of course be understood that if two stages of the kind indicated by 1st in Figure 2b are available and can be disabled and assuming that both were added to the first active stage A as outlined above, then the charge to be transferred in one cycle would be $Q = 3 I_{\text{load}}/8f$. Any number of available stages, which can be disabled, can be added to the first active stage A according to the preferred embodiment.

Clearly, when the output capacity C_{buffer} of the charge pump is heavily loaded, the present embodiment helps to alleviate the effort. The improvement has been examined in several experiments. In particular, the effect of the improvement has been simulated with a charge pump device with five stages, i.e. 6 charge pumps, for which the 1st stage has merely been used as outlined in Figure 2b to increase the equivalent capacitance of stage two or a higher stage in the cascade. The result of the simulation proved that a preferred embodiment 1b is able to achieve the same voltage within seven clock cycles, as compared to eight clock cycles needed by a conventional device 1a of Figure 2a. One cycle less is needed by a preferred embodiment. If one considers the load current I_{load} required in order to achieve the same voltage with the prior art approach of Figure 1a and the outlined approach of the preferred embodiment of Figures 2b and 2c of merely improving the first stage in the cascade, the improvement amounts to 12.5 % in the current capability. Consequently the prior art charge pump would give 12.5 % less current for the same voltage. In other words, a conventional device would take 12.5 % more time to recover from a large peak of current absorbed by the load.

This improvement is even more effective considering the fact that the above example has been outlined without taking any load current and any losses for achieving $(N_{\text{stages}} + 1) \cdot V_{\text{dd}}$ into consideration. However, as there is usually a load current in charging, the voltage generally achieved is lower. To obtain a voltage under
5 load conditions, usually the pump has to be over-dimensioned by an increased number of stages in the cascade. Therefore, the input voltage range usually has to be larger than in theory. In order to achieve the target output voltage V_{out} most efficiently the number of active stages can be programmed to address a variety of applications. If there is a sufficient input voltage V_{dd} , one or two stages may be disabled by software. By
10 operating those stages in such a way that they increase the value of the first capacitor one is also able to benefit from the increased current capability. In fact, this is achieved without any area being wasted, as the proposed concept may more or less be achieved by merely changing the decoder logic for the bottom plate drivers. Such a decoder is of low voltage and small compared to other devices. Usually the decoder comprises only
15 several logic gates.

To realize the proposed scheme changes have to be made only for some few items of a charge pump device 1. The logic which controls the bottom plate drivers of the stages $S_1 \dots S_N, S_{N+1} \dots S_{\text{max}}$ in the cascade has to be modified as proposed with the preferred embodiment of Figure 2b. As a consequence of the proposed charge pump
20 device the voltage on the second pumping stage capacitor A in the preferred embodiment differs from the one of a conventional device as outlined in Figures 2a and 2b. In fact, under the outlined conditions of load V_{dd} and target voltage V_{out} , the proposed concept is the only one to obtain a current efficiency increase in the amount shown above.

25 In summary, the proposed concept allows to realize a re-configurable charge pump software architecture. The benefit of this is the increase of the current capability should the wanted multiplication factor be lower than $(N_{\text{stages}} + 1)$.

The field of application of an improved charge pump may be any driver for a grayscale or a color display. As outlined in Figure 3 such a display 11 may be any
30 display for a LCD or PolyLED technology or any other application needing a voltage booster working under current loads of 0.1 mA to 10 mA. The preferred embodiment of

a driving circuit 12 may be part of a display module 11, built with an LCD cell 14 and additionally a display driver IC 12 as proposed. The IC 12 is preferably mounted on glass. Also such a display driver IC could be connected (15, 15a) with TCP or a foil. A charge pump 12a, as a preferred voltage converter embodiment, is part of the illustrated

5 driver IC 12 of Figure 3, as a preferred driving circuit embodiment. The charge pump provides the high voltage necessary to drive the LCD cell 14. The display module may be built, for example, in small portable devices 10 as cellular phones and Personal Digital Assistants (PDAs) as shown in Figure 3.